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A review of the causes, impacts and solutions for electricity supply crises in Brazil

Julian David Hunt.[a,*], Daniel Stilpen[b], Marcos Aurélio Vasconcelos de Freitas[b]

[a] International Institute for Applied Systems Analysis, IIASA, Scholssplatz 1, A-2361, Austria
[b] Energy Planning Program/COPPE/UFRJ, Brazil

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ABSTRACT

From the end of 2013 to the end of 2015, Brazil faced serious challenges to supply its demand for electricity due to a prolonged drought in the Southeast and Northeast regions with the consequent loss of hydroelectric generation. This paper presents an historical analysis of major world energy crises from 1988 to 2015 and in Brazil from 1924 to 2015. Analysing the natural river flow of key Brazilian dams from 1931 until 2017, this paper suggests that hydropower generation in Brazil has a 10–15 years cyclical pattern of hydropower generation. The periods of drought in this cyclical pattern usually coincides with energy crises due to the reduction in hydropower generation. It was found that the drought in 2015 had an impact of 110 TWh in hydropower generation, from which 25 TWh are due to head loss and 70 TWh are from lack of stored hydropower in July of 2014. In addition, 48 TWh were not generated due to delays in the construction of new power plants. Other causes of the Brazilian energy crisis of 2015 are presented and the overall electricity generation impact of these causes are compared. In addition, this paper presents the impacts on the energy, water and food supply sectors in Brazil, and the strategies employed to reduce the impact of the crises. With the intention of preventing future energy crises, the paper then shows the potential alternatives to improve electricity supply security in Brazil, particularly in terms of diversifying and widening the share of renewable sources and increasing the energy storage potential of the country.

1. Introduction

Electricity sector crises originate for different reasons, such as Nuclear power disasters, for example, in Fukushima, Japan [1], unregulated energy markets as in California [2,3] and Chile [4], rapid surge electricity demand and sluggish investments in the electricity sector as in Pakistan [5–8] and Bangladesh [9], macroeconomic crisis as in Argentina [10], extended droughts affecting hydroelectric generation as in Nepal [11] and Brazil [12]. Details on the major causes and resulting actions for these crises are presented in [13–16]. Looking at the bigger picture there is a global energy change happening with the aim to replace fossil fuel alternatives for renewable energy sources, with all the resulting consequences [17].

With the intention of providing secure [18] and affordable electricity supply services, countries have implemented regulatory reforms in the electricity supply industry [10,19]. However, some regulations are applicable to one country but not to others [20]. Electricity supply and crisis management is a particularly complex issue in developing countries in Africa, such as Ghana, Cameroon, Ethiopia, where most of the population does not have access to electricity [21,22].

This paper attempts to describe some of the causes and impacts of the energy and water crises in Brazil, and proposes some suggestions for improvement. The main contributions of this paper are to highlight that Brazil has been suffering from an energy crisis with a frequency of 10–15 years, i.e. the years 1924, 1944, 1955, 1964, 1986, 2001 and 2015. This crisis pattern is due to systematic and climatic problems that should be resolved with short, medium and long-term measures as proposed in this article. In addition, this article highlights the main impacts from the energy and water crises so that strategies can be made to better prepare for future crises, and propose possible solutions to prevent future energy crises.

Historically, the power sector in Brazil has been plagued by multiple power crises of different duration and geographical scope. In the great majority of the cases, the causes of the crises were associated with

Abbreviations: ANEEL, Brazilian Electricity Regulatory Agency; ECS, Energy Crop Storage; EPE, Energy Research Office; GDP, Gross Domestic Product; IBGE, Brazilian Institute of Geography and Statistics;; ONS, Brazilian Electricity Grid Operator; PDE, Ten-Year Energy Plan; PLD, Spot Market Electricity Price; SIN, Brazilian Interconnected Electricity System; SPS, Seasonal-Pumped-Storage

* Corresponding author.
E-mail addresses: hunt@iiasa.ac.at (J.D. Hunt.), stilpen@ppe.ufrj.br (D. Stilpen), mfreitas@ppe.ufrj.br (M.A.V. de Freitas).

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Table 1
Previous crises in Brazil and their main causes [13,24,27].

Period	State/Regions	Major causes
1924–1925	São Paulo	Drought in Tietê river and its tributaries.
1938–1947	São Paulo	Difficulty to import equipment due to World War II.
1950–1957	Southeast	Drought and demand increase.
1951–1964 (intermittent)	Rio de Janeiro	Drought in Paraíba river and lack of generation capacity.
1963–1964	São Paulo Rio de Janeiro	Drought: drastic reduction in river flow in the Paraíba and Piraí rivers.
1967	Rio de Janeiro	Flooding of Nilo Peçanha Plant.
1986	South	Drought in the Southern Region.
1987–1988	Northeast	Drought in the Northeast Region.
1995–1999	Manaus	Lack of investment due to poor regulations.
2001–2002	Nationwide, except in the South Region	Drought in the Southeast, Northeast and North regions, and delay in the expansion of thermal generation and transmission lines.
2014–2015	Nationwide	Drought in the Southeast, Northeast, South and North regions.

climatic conditions, since Brazil has historically been very dependent on hydroelectricity [13]. The first recorded energy crisis in Brazil happened in 1924–1925 with a drought in the Tiête river and affected the city of São Paulo. Table 1 presents the previous crises in Brazil, including their respective reasons and the main impacted regions. Another intense energy crisis happened between 1953 and 1955, when the hydropower stored in the reservoirs reached very low levels and there was energy rationing in the cities of São Paulo and Rio de Janeiro. The power outages reached 5–7 h a day in Rio de Janeiro. In São Paulo power cuts, without prior notice to the public, were quite common [23]. Both cities were again subject to rationing in 1963 and 1964, as the country faced an accelerated growth in the consumption of electricity and the investments failed to attend the increase in consumption [24]. In 1986, the Southeast region was threatened by electricity rationing, as occurred in the South region in the same year [13]. Emergency measures were taken, such as daylight saving time throughout the national territory [25]. Rationing also occurred in the Northeast between March 1987 and January 1988 due to two basic causes: the first, due to the low volume of water in the São Francisco basin and the second due to the delay in schedules of planned hydroelectric projects, caused by financial problems [13,26].

In 2001, five years after reforms in the energy sector, Brazil went through a severe energy crisis, which by far dwarfed the previous crises in size, duration, geographical scope and complexity [13]. A dry summer[1] arrived when the water levels of the Brazilian dam system were at low levels, leading to a water shortage that culminated in a rationing of electricity consumption with penalties for over-consumption. Unclear market rules led to major lawsuits from different parties, leaving the electricity market in chaos. The official government explanation for the crisis was the unexpected drought of the first months of 2001 that added to a series of unfavourable rain falls in the previous years, 1999 and 2000, leading to the acute water shortage of 2001 [28]. The maximum storage levels for each year were 1998 – 83%, 1999 – 70%, 2000 – 59%, 2001 – 41% [29].

From June 2001 to February 2002, Brazilians were obliged to restrict electricity usage by 20%, on average. During the 1990–2000 period, there was an increase of 52.3% in electricity consumption, whereas total generation capacity increased by only 41.2%. The gap between consumption and installed capacity contributed to the inevitable collapse in 2001 [30].

Several papers have been published about the 2001 energy-rationing crisis. Franchito and Rao (2008) [31] proposed a climatological methodology to predict droughts in the Southeast of Brazil so that the energy sector can respond appropriately to reduce its impact. Simões and Barros (2007) [32] highlighted that loss of water through evaporation-transpiration impacts hydropower generation during a drought, increasing its vulnerability to changes in climate. Souza and Soares (2007) [33] argued that the electricity demand was not significantly reduced through electricity conservation campaigns and the Government's request to reduce consumption. It only leads to a considerable reduction when compulsory electricity cut-offs would be implemented if the customer did not reduce consumption. Araújo (2006) [12] gives a detailed analysis of the Brazilian energy market reform, its impact on the 2001 crisis and also lists the causes [34]. Cavaliero and Silva (2005) [35] argued that the 2001 crisis increased debate on the need to diversify the grid, reducing the share of hydropower and increasing generation from other renewable energy sources, which is similar to what is happening at present. Other authors blame the crisis of 2001 on unfinished structural and institutional reforms [36–42] and on gas-fired power development project finance issues [43–45].

As shown in Fig. 1, in July 2001, the monthly demand had to be considerably reduced, because there was not enough energy stored in the Southeast hydropower dams to safely guarantee electricity supply for the following years. The government then decided to reduce energy consumption for residential consumers by 20% and for industrial and commercial consumers by 15–25%, depending on the importance of the economic activity [46], so that the demand would fall and the reservoirs could then fill up again [33]. The Aluminium industry suffered the hardest impact from energy rationing [47], other industries also suffered with the crisis, including the paper industry [48]. The impact of the energy crisis could even be seen from space at night, due to the reduction in lighting [49]. During this period, energy efficiency programs were established for people switching from incandescent lightbulbs to fluorescent lightbulbs [35], to replace old refrigerators for more efficient models, among other energy saving measures. This resulted in a considerable demand reduction. As it can be seen in Fig. 1, the demand only returned to previous levels in 2004 as the energy and economic crisis reduced the demand for electricity.

Since 2001 much has happened to reduce the risks of a new energy crisis. Transmission lines were installed, increasing the ability to transfer electricity from one region to another (in 2001, the energy that could have been generated in the South or in the North could not be transferred to the Southeast and Northeast due to lack of transmission lines). The country also received considerable generation capacity reinforcement, which reached 42 GW of thermoelectric power plants and other renewables in 2014 [51].

Even with these improvements to the Brazilian energy sector, in 2015 a similar trend happened due to a severe drought on the Southeast and Northeast regions caused by climate variability or climate change. The volume of water in the reservoirs fell below that of 2001, to 19%. As Brazil is still heavily reliant on hydropower generation, the hydropower generation share decreased from 91.9% to 71.3% between 2011 and 2015 [52], as shown in Fig. 2.

Hydropower reservoirs reached dangerously low operational levels that forced the Brazilian Electricity Grid Operator (ONS), to halt hydropower generation in the dams that exceeded its dead storage volume. To meet the demand, most available thermal power plants in the

[1] Summer is the rainy season for most part of Brazil.